

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY)		2. REPORT TYPE		3. DATES COVERED (From - To)	
15-12-2005		Technical Note		1 Oct 2005 - 1 Dec 2005	
4. TITLE AND SUBTITLE What Does the Military Biomedical Research Contribute to Sustaining Soldier Performance in Cold Environments?				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER PE 62787	
				5d. PROJECT NUMBER Project 879	
6. AUTHOR(S) COL Karl E. Friedl				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Institute of Environmental Medicine Natick, MA 01760-5007				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command ATTN: MCMR-PLC (Military Operational Medicine Research Program) Fort Detrick, MD 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Unlimited Distribution					
13. SUPPLEMENTARY NOTES This report was prepared in conjunction with presentations to the Oslo Military Society and the Third Norwegian International Defence Seminar (NIDSIII) at Gamle Logen, Oslo, Norway, in October 2005					
14. ABSTRACT Research on the physiology of performance limits provides simple and effective solutions involving the way we feed, train, and equip the Soldier. Accurate predictions of human performance offer useful decision aids to military planners, set safe limits in training, and provide a scientific basis to evaluate military strategies or off-the-shelf technologies. Current cold physiology studies focus on hypothermia risk prediction, militarily-relevant performance, and affordable metabolic countermeasures. Joint Norwegian-U.S. research cooperation on extending human limits in cold environments is a logical expansion of previous productive Norwegian Defense Research Establishment (NDRE)-USARIEM studies, with new opportunities and requirements presented by Norwegian leadership in NATO cold weather training.					
15. SUBJECT TERMS thermal physiology; research management; international collaboration; Norway; performance; military operational medicine research; RAD3; laboratory and field studies; military relevance					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			COL Karl E. Friedl
U	U	U	unlimited	19	19b. TELEPHONE NUMBER (include area code) 508-233-4811

USARIEM TECHNICAL NOTE T07-13

**WHAT DOES MILITARY BIOMEDICAL RESEARCH CONTRIBUTE TO
SUSTAINING SOLDIER PERFORMANCE IN COLD ENVIRONMENTS?**

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December 2005

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ACKNOWLEDGEMENTS

Drs. John Castellani, William Santee, Xiaojiang Xu, and Reed Hoyt have performed much of the cold physiology and modeling research described here and I am grateful for their critical review of this paper.

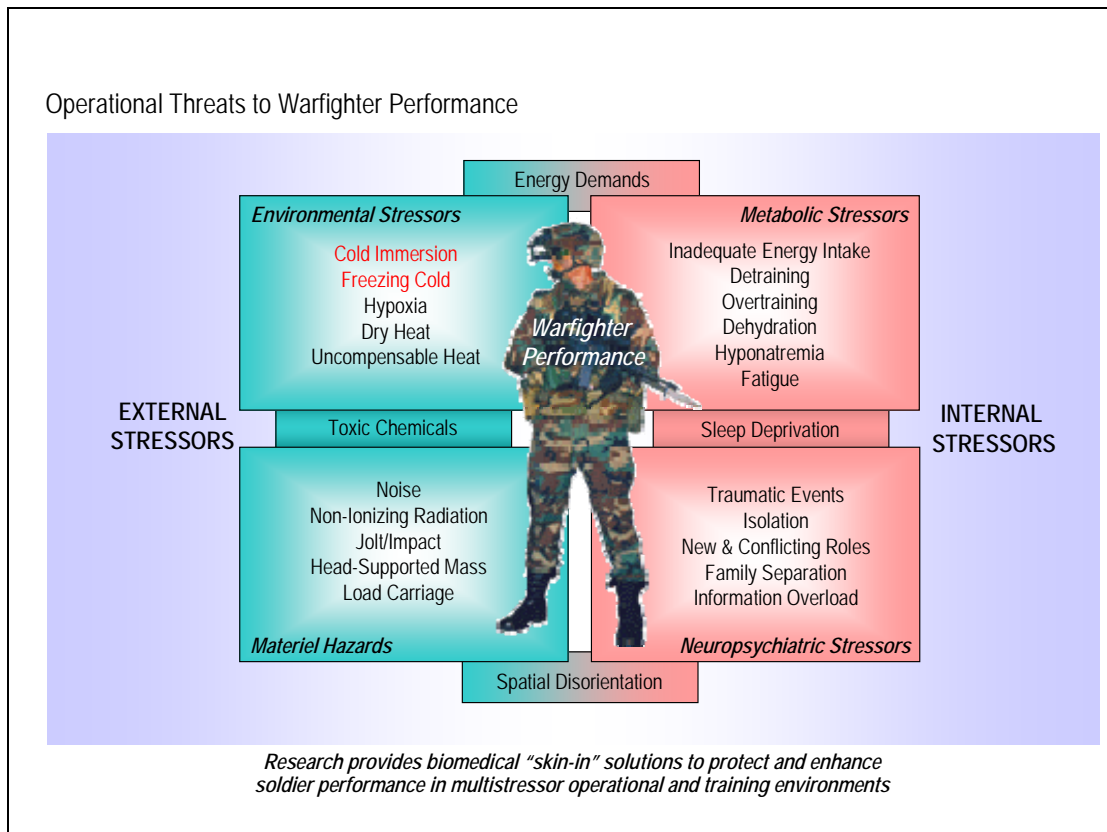
EXECUTIVE SUMMARY

Research on the physiology of performance limits provides simple and effective solutions involving the way we feed, train, and equip the Soldier. Accurate predictions of human performance offer useful decision aids to military planners, set safe limits in training, and provide a scientific basis to evaluate military strategies or off-the-shelf technologies. Current cold physiology studies focus on hypothermia risk prediction, militarily-relevant performance, and affordable metabolic countermeasures. Joint Norwegian-U.S. research cooperation on extending human limits in cold environments is a logical expansion of previous productive Norwegian Defense Research Establishment (NDRE)-USARIEM studies, with new opportunities and requirements presented by Norwegian leadership in NATO cold weather training.

INTRODUCTION

The U.S. Department of Defense funds and conducts biomedical research to solve important Soldier problems, provide options to the military, and to avoid technological surprise. This includes the physiology of human performance, an area of specialization that is not well addressed anywhere else in U.S. government-sponsored research. The U.S. Army Research Institute of Environmental Medicine (Natick, Massachusetts), USARIEM, supports this effort as the primary biomedical laboratory on sustaining human performance in the face of environmental and occupational stressors. Many of the most effective solutions derived from this research are simple and involve the way we feed, train, and equip Soldiers. These solutions come from an understanding of complex physiological processes that protect an organism against external challenges, discovered through basic laboratory animal studies, clothing testing, human experiments in the laboratory and the field, and biomathematical modeling and prediction of the quantitative responses. Although mankind has considered these issues over centuries, technological advances continue to accelerate the pace of understanding in physiological regulation. These breakthroughs provide a systematic basis for optimization of the Soldier in stressful environments (Figure 1). The advantages and options that are created by such research are commonly overlooked, in part because commanders have a practical understanding of limits and may feel that science has little to add, and because researchers do not consistently make their discoveries and expertise useful to the Army. However, the appreciation for human performance research by commanders has been improving as military researchers work harder to be relevant.

Figure 1. Operational threats to warfighter performance. This figure highlights key stressors acting on the Soldier in military training and operational deployments currently studied in the military operational medicine research program. Critical research needs are (1) to understand the important stressor interactions, as Soldiers are rarely subjected to only one stressor at a time, and (2) to be able to predict consequences to performance, including effects on various domains of mental status (e.g., cognitive, emotional, and psychomotor).



HOW DOES SCIENCE GET TO THE SOLDIER?

A cornerstone of science is the peer review that comes from public presentation and publication of new results. Studies that are not reported were essentially never done. Study results that are not externally reviewed, critically discussed, and confirmed carry the highest risk of being incorrectly interpreted and applied. Reporting military medical findings also helps encourage otherscientists to work on problems of importance to the military. While scientific publication is necessary, this is not sufficient for military research; the scientists must also put useful knowledge from this research into the hands of the right military customers. In this “product line” of optimizing the physiology of the healthy Soldier, the translation of research discoveries into practical applications for the U.S. Army has generally occurred through three different categories of research customers: materiel developers, combat developers, and preventive medicine experts (Figure 2). Recommendations that will enhance personal equipment such as rations or clothing are transitioned to the Research Development and Engineering Command (RDECOM), specifically the Natick Soldier Center (Natick, Massachusetts)(collocated with USARIEM). Application of training methods and stressor countermeasures are developed by the Training and Doctrine Command (TRADOC), often with field testing and transition of research concepts by the Infantry Center (Fort Benning, Georgia). Preventive medicine specialists develop policy and guidance at the Army Medical Department Center and School (AMEDD C&S, Fort Sam Houston, San Antonio, Texas) and disseminate the information to the Army through the Center for Health Promotion and Preventive Medicine (CHPPM, Aberdeen, Maryland). The products of this biomedical performance research are not restricted to medics but, in fact, usually go into the hands of every Soldier with the intention of keeping Soldiers healthy and out of medical channels.

Figure 2. Who uses this research? There are three key research lines, or customers, of Military Operational Medicine research. In the example of cold research, models to predict clothing insulation requirements in cold environments are important to materiel developers at Natick Labs; predictive models of immersion cold limits to protect Soldiers against serious injury in high intensity training such as Ranger school are priority topics for TRADOC; nutritional and pharmacological interventions to enhance performance through metabolic stimulation and sustained manual dexterity in the cold are of interest to combat developers such as the Dismounted Battlelab at Fort Benning.

Who Uses this Research?

<p>Materiel developers (e.g., NSC, PEO-Soldier) <i>Example: Performance enhancing ration components</i> <i>Example: Uniform/personal equipment biophysical evaluations</i></p>	 Natick Soldier Center
<p>Preventive medicine (e.g., TRADOC, CHPPM) <i>Example: Rapid physical train-up with simultaneous injury reduction</i> <i>Example: Heat prevention guidance and implementation</i></p>	 CHPPM
<p>Combat developers and others (e.g., AMEDD C & S, MOUT/Dismounted Battle labs) <i>Example: Warfighter Physiological Status Monitor-Initial Capability</i> <i>Example: Rapid altitude acclimatization</i></p>	 AMEDD C & S
<p><i>We don't make the Soldier's equipment, we help make the Soldier's equipment better...</i></p>	



WHAT HAVE MILITARY SCIENTISTS DONE FOR THE SOLDIER LATELY?

On the great research tree, there should be frequent “low hanging fruits” that can be picked for the Army; if the tree gets care and feeding and continues to grow - but never produces fruit for the Army - it has served no useful purpose, no matter how beautiful the flowers (or how wonderful the science). Cold

physiology research is an example of a fruitful research “tree.” In World War II, the U.S. Army conducted quick studies on men exercising on treadmills in cold chambers to estimate clothing needs before dropping them into the Aleutian Islands (19, 20), where water landings and other unanticipated cold challenges still caused large numbers of casualties; little further research was conducted before new problems with cold injury occurred in the Korean War (23). As a result of several decades of new research, the prognosis for Soldiers in cold weather environments is much different in 2005 (14). The U.S. Army is releasing the third generation Extended Cold Weather Clothing System (ECWCS III) for issue to units in Afghanistan this winter (13). This system includes seven layers of modern light-weight and breathable insulation materials that overcomes many of the previous problems of impervious clothing that created a semi-tropical microenvironment in which Soldiers would sweat and then become cold, and which increased energy requirements because of the hobbling effects of the heavy clothing (12). New water immersion exposure guidelines have been issued for high intensity training, such as Ranger school, where deaths from hypothermia occurred unexpectedly in healthy but stressed men; these guidelines are being further refined to finally provide accurate and realistic training safeguards that are based on a thorough understanding of operational factors that can increase cold injury risk. Just over the horizon, a new tyrosine enriched “stress” snack may help to sustain mental function in cold stressed Soldiers; physiological testing may reliably identify individuals at special risk for environmental cold injuries; and new equipment and ration composition may enhance metabolic responses to maintain extremity blood flow and manual dexterity. Younger sprouts on the research “tree,” such as genomics studies that systematically identify advantageous cold adaptations, will yield more options for commanders of the future. Even more basic academic investigations are funded by the Army in academic laboratories on topics such as antifreeze proteins from cold water fish to help keep the military on the leading edge and avoid technological surprise in this important area of human performance limits.

WHY NOT BUY THIS RESEARCH “OFF-THE-SHELF”?

An effective ongoing military research program is needed to ensure relevant “on-call” expertise, and an ability to immediately address cold problems from the field based on a depth of understanding not available from test and evaluation programs. When we sent troops into Afghanistan in the cold and at altitude, USARIEM scientists had only days to provide updated guidance to assist in cold weather/altitude operations; this would probably not have been possible without an applied research group focused on military needs.

The new ECWCS was developed by Natick Soldier Center. Behind the scenes in this materiel development is not only years of research on new fabrics and clothing technology but also medical technologies that evaluate thermal properties, including insulation and vapor transmissibility and predicted human responses (17, 25, 26, 32, 33, 40). This involves the development of physiological models that predict Soldier heat balance during normal Soldier activities and the ability to make accurate predictions from efficient evaluations on sweating articulated copper manikins, feet, hand, and head models (32, 35, 38). The accuracy of the models and human factors aspects have largely been confirmed with Soldiers exercising and conducting other Soldier tasks in cold chambers with wind chill, and in the field. Most commercially available cold weather equipment is not developed through this rigorous process, or even a comprehensive test and evaluation process, but rather by guesses and anecdotal evaluations. The products of a military research program would help improve test and evaluation programs and constantly advance the science so that it becomes easier to solve new but related problems. Continuous improvements in mathematical modeling of physiological data and accumulated discoveries of physiological principles will lead to “virtual prototyping.” Ultimately, computer programs will be available that can be used to specify the desired properties of materials for optimal human physiological performance for various environmental conditions and operational requirements.

Military scientists devote a significant amount of time to protect Soldiers against possibly well-intended but bad ideas from the commercial sector. Performing this function also calls for scientific depth to ensure that the military does not inadvertently reject a revolutionary advantage but also does not invest time and money in ideas that are simply bad science. An example of this was a proposal to provide a very high fat (energy dense) ration to Soldiers on the basis that some cold weather explorers and natives have existed successfully on pemmican. This had been tested by both Canadian and U.S. military forces in the 1950s and didn't require new studies to confirm that it was a bad idea for a ration that would have required lengthy gastrointestinal adaptation, would never be well tolerated by some individuals, and would not have provided the optimal fuel for Soldiers working hard in the cold (22, 24, 34).

DOES NEW COLD WEATHER GUIDANCE SIMPLY DUPLICATE COMMON SENSE AND GOOD TRAINING?

New discoveries in Soldier performance are emerging from studies of the interactions of operational stressors, in part, because this is a relatively new frontier compared to all the studies of single isolated stressors. Some surprises have emerged, such as a recent finding that dehydration in the cold has much less effect than expected on performance (over the significant effects of cold exposure alone)(11). This finding has implications for logistical priorities (potable water supply) in cold versus hot weather operations.

An important example of non-intuitive findings comes from experience with hypothermia in conditions that would have normally been tolerated by a well-rested and fed Soldier. After several fatalities in the swamps of Florida during winter Army Ranger training in 1977, the Army established water immersion exposure limits; these were constructed from the best available knowledge at the time (18). In 1995, four more students died in water above 52 F and were probably in trouble before the 3 hour limit permitted for waist-deep water exposure (16). While other factors probably contributed to lives lost, clearly,

academic science and human judgment both failed to account for the circumstances that significantly altered the risk. Subsequent research has provided new understanding of some important stress interactions that affect thermoregulatory predictions for the Soldier. Repeated immersions in the same day (such as walking through streams of various depths) produced a “thermoregulatory fatigue” previously unrecognized in science and not readily explained by glycogen depletion (10). Acute exercise (e.g., a physically exhausting road march) and chronic exercise (e.g., daily 4 hour bouts of hard work) reduced the ability to conserve heat (8, 9). At the end of Ranger training, some of the abnormal shivering and heat production responses recovered after several warm meals and sleep despite the loss of fat insulation, demonstrating the importance of adequate daily feeding and rest for optimal Soldier performance (29, 39). From sophisticated research modeling, reasonable assumptions about clothing, body fat and other characteristics, proper partitioning of knee, waist, and neck depth exposures, and environmental factors and stressors can be tested to generate even better immersion guidance.

Other studies, such as a laboratory-controlled multiple stressor study (7) and a disabled submarine study in USARIEM test chambers (6) continue to produce new data on cold exposure modeling of safety and survival. New studies of mental performance and manual dexterity (e.g., assembly and disassembly of a weapon) during combined cold immersion, cold air exposures, and borderline hypothermia have generated data that will lead to more accurate predictions of performance and mental functioning. The product of the complex laboratory physiological model may be an easy-to-use decision support tool for the commander of the future. Simple queries based on weather, terrain, uniform clothing and key physiological variables will yield accurate and practical predictions. These more accurate models will provide more realistic training in warfighter simulations such as role-playing games that penalize the players appropriately when Soldier health or performance deficits compromise mission success. Thus, some life and death lessons can be first learned in the virtual

world. Decision support tools with simple interfaces and outputs for military planners, commanders, and preventive medicine specialists can be readily constructed from the data, lessons, and subject matter expertise available.

NEAR FUTURE WORK – TECHNOLOGICALLY SOPHISTICATED RESEARCH TO PRODUCE SIMPLE BUT EFFECTIVE AFFORDABLE SOLUTIONS

The current focus of cold physiology research at USARIEM is on sustaining mental performance and manual dexterity. The likely solutions are linked to metabolic flux regulation, possibly through foods or special supplements, and possibly through manipulation of warming or cooling specific body regions to influence regulation of blood flow to the hands. One of the most promising near-term recommendations may come in the form of a neurocognitive enhancer – a tyrosine food supplement. This amino acid is found in normal food and provides the substrate for several important neurotransmitters that are reduced in high stress conditions. When needed in high stress conditions, tyrosine availability appears to be a limiting step in sustaining cognitive function. With significant cold stress, short term memory is substantially impaired; placebo-controlled studies demonstrate that eating a tyrosine food bar reverses these cold-induced performance deficits (2).

Manual dexterity is influenced by cyclic increases in blood flow to the hands (the Lewis “hunting” reaction). Gaspe fisherman and Inuit hunters who can reach into very cold water to remove their catches with bare hands are thought to have robust physiological mechanisms that maintain this alternating blood flow response; at the opposite extreme, individuals with cold injury and various other forms of peripheral vascular disease vasoconstrict without this relief and rapidly develop cold, painful, and clumsy hands when exposed to cold. The maladaptive responses can be predicted from a simple cold water finger immersion test (CIVD – cold-induced vasodilation) (27, 36), but in normal individuals, this hunting response can be improved by increasing torso

temperature either through external heating, additional clothing insulation, or possibly through thermogenic supplements that increase metabolic heat production. Caffeine and ephedra combinations appear to be very promising in increasing heat production in the cold, but ephedrine has been banned in the U.S. because of possible health risks. Other dietary solutions may be possible; a normal meal provides a thermic effect of its own, while underfeeding reduces body temperature (31) and may affect even manual dexterity through changes in peripheral circulatory responses. Currently under investigation are the effects of specific regional temperature signals such as cooling or heating the face, and its effect on peripheral blood flow. Outcome measures in our lab include Soldier-relevant tasks such as assembly and disassembly of weapons, marksmanship, and working memory. Conceivably, the result of these studies could be strategies as simple as covering the face and recommendations to consume normal meals, if continued dexterity of bare hands in the cold is a vital requirement.

THE WAY AHEAD – NORWEGIAN-U.S. COOPERATION

NDRE research studies of stress responses at the limits of human performance with food and sleep deprivation and continuous work have blazed a trail for other scientists, and represent some of the most frequently cited scientific studies and methods in this area (1, 3). This research provided the scientific foundation for USARIEM studies of U.S. Army Ranger students, that led to practical solutions to improve safety for high intensity training (28, 37). It has also grown into direct cooperation with joint studies that have helped to advance physiological monitoring, providing the first realistic test of wearable sensors to identify a minimal sensor set for useful information to a commander about the status of their own Soldiers. Joint studies of male and female Norwegian cadets have led to the discovery that more efficient fat utilization in women may provide some special advantages that could influence the design of future rations (21). Nutrient partitioning properties of rations that favor fat metabolism, and even

customized rations that consider gender, may become an important next step in individual performance optimization. A joint study of overtraining took advantage of the trans-Greenland (“G2”) expedition experiences of Rune Gjeldnes and Torry Larsen (15). This study demonstrated that contrary to an anticipated physical breakdown from the prolonged exhaustive work, individuals could complete such a task with absolutely no degradation of their health and physical capacity if they had good training, preparation, and adequate energy intake.

In the future, shared databases could further test and enhance predictive models and simulations, biological sample repositories could be shared for genomic and immune function studies (5) on cold injury susceptibility and physiological resilience, fatigue and psychological stress (4, 29, 30), and many more studies could be accomplished jointly and using common measures and monitoring technologies to test performance limitations and benefits of new countermeasures.

Research discoveries constantly improve current answers through evolutionary advance but also provide unpredictable “revolutionary” breakthroughs that fundamentally change our understanding (Figure 3). Research discoveries are not predictable; however, the probability of important discoveries occurring increases when resources, especially good scientists, are applied to a problem. This reality calls for continuity, with experts and their successors trained in the unique physiology requirements of the military. Leveraging brain power between similarly specialized laboratories such as NDRE and USARIEM can increase the speed of research for Soldiers.

Figure 3. New discoveries in physiology of multiple stressors. The experiments conducted in the military operational medicine research program integrate findings from basic laboratory research to overcome technology barriers and applied field research to test models, hypotheses, and interventions. Applied research can verify the importance of basic mechanisms identified in the lab, and lab studies produce new knowledge for revolutionary advances in protection of Soldier health and performance.



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